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The Brazilian experience of rural electrification in the Amazon with decentralized generation – The need to change the paradigm from electrification to development

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ABSTRACT

There are at least 607 thousand households in the Brazilian Amazon that need to be attended with some form of regular electricity service. These households are not attended by the electricity sector through its electricity distribution companies and most of them have some form of precarious decentralized electricity generation that is not registered or regulated in the institutional framework. Diverse initiatives were taken by Brazilian government to attend these household through alternatives that relied on locally available renewable energy. This paper accesses this initiatives of rural electrification in the Brazilian Amazon. First an overview of the problems of rural electricity are discussed and its specificities in the Brazilian Amazon. Then the Brazilian institutional framework that organizes the decentralized electricity generation is described with its various limitations. The diverse initiatives undertaken to attend the rural communities in the Amazon since the 1990s are described, as well as how these initiatives are linked to the policies for rural electrification. The results shows that it can be inferred that sole market mechanisms are not sufficient to guarantee economic sustainability of these projects. This can be one of the reasons why traditional electricity distribution companies showed the lack of interest in promoting rural electrification with other means than grid extension. The most successful projects had financed efforts to integrate the generation of electricity into local development initiatives in order to guarantee sustainability and used substantial part of funding for local mobilization and organization. It needs a paradigm chance by treating these initiatives as local development initiatives and promoting alternative ways for its implementation through partnership between local new actors in the electricity sector and government and implementing policy on a local municipal level.

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1. Introduction

The Brazilian Amazon is an hinterland with 3.85 million km^2, occupying almost 30% of the territory of south America with a population of 14 million inhabitants. More than 8.4 million of its inhabitants live in the metropolitan capital cities and in the thousands of urban cities and conglomerates that define the occupation of this large territory. But the essence of the Amazon is its rural area, because it provides its wealth in all aspects.

Even with a very low population density of 3795 inhabitants per square kilometer, human presence is very significant in the rural areas and so is its needs for basic social and economic infrastructure for development. The overall human development indicators show that the rural area of the Amazon is far from attending the living standard that ensure sustainable in these rural communities.

Among all the basic social and economic infrastructures, access to energy services for these local rural communities is crucial to boost community based development. Energy services are essential to both economic and social development and that much wider and greater access to energy services is critical in achieving all of the Millennium Development Goals of the United Nations.

Within the energy services, electricity is critical for providing basic social services as water supply and purification, sanitation, and refrigeration of essential medicines. Electricity can also power machines that support income-generating opportunities. Pereira et al. [1] shows that the absence of electricity tends to accentuate the existence of social asymmetry in living conditions and describes how rural electrification has a strong impact on the reduction of energy poverty. Lack of modern energy services can decrease the willingness of more-educated workers (such as teachers, doctors, nurses, and extension agents) to reside in rural areas, further limiting services and opportunities to local population [2–4].

The most recent data from the Brazilian Institute of Geography and Statistics shows that there are 58,577 thousand households in Brazil of which at least 637 thousand had no form of electric light (illumination) in 2009 [5]. Out of these households without electric light, 163 thousand are situated in the Amazon region.

The problem related to electrical energy for remote communities in the Amazon has its origin in several factors. The very characteristics of the communities in general are not favorable for promoting rural electrification. Traditional extension of the distribution network is not always a reliable technical and economical option, because of the extensive geographical area with dispersed communities, and also because of the low demand which increases the installation cost of the distribution network.

Expansion of the electrical network usually depends on road infrastructure. However, a significant part of isolated communities in the Amazonian area, are not accessible by road, but by boat. Thus, the electricity has to be provided through decentralized generation. The consolidated technological solution for this option is using diesel motors. There are various types and models of diesel generators sets commercially available, ranging from those with a few hundred watts to some generating hundred thousand of watts. However, the high acquisition and transportation cost of the diesel fuel makes this option very expensive.

Besides traditional generator sets with diesel fuel, there were also several initiatives with alternative electricity generation using locally available renewable energy sources, such as solar, wind, hydroelectric, and biomass energy. The use of these alternatives eliminates the need for fossil fuel supply, avoiding the high acquisition cost and the complex logistics of distribution. That's why generating decentralized renewable energy has been gaining attention as one of the most suitable options for electrification, particularly in isolated communities; almost all of these communities have local renewable energy sources which can be used to guarantee the supply of electricity.

This paper presents the situation of rural electrification in the Brazilian Amazon and the initiatives undertaken to bring electricity for the thousands of isolated communities that need to have a form of decentralized electricity generation to attend its needs.

First an overview of the problems of rural electricity are discussed and its specificities in the Brazilian Amazon. In the next section the Brazilian institutional framework that organizes the decentralized electricity generation is described with its various limitations. The diverse initiatives undertaken to attend the rural communities in the Amazon since the 1990s are described, as well as how these initiatives are linked to the policies for rural electrification.

2. Electricity in rural areas and rural electrification

The electricity issue in rural areas cannot be solved as a simple problem of demand and supply, or as a mere logistic problem to provide electricity services. De Gouvelle [6] in his analysis of the rural electricity situation shows that the problem of rural electrification is in its genesis as the rural areas became more dependent on the new intermediary energy products and less on natural energy resources. These new intermediary energy products emerged such as coal/steam, electricity, diesel, gasoline and liquefied petroleum gas (LPG) surged in the context of urbanization and industrial revolution. The demand on economic efficiency of these energy products resulted in an increase in economics of scale and, as a consequence, energy production became more centralized in larger power plants, with wide distribution networks and complex logistics for its delivery.

In essence, natural energy resources were transformed into merchandise, but this kind of extraction of energy from nature, and its transformation into something independent, did not happen in traditional agricultural systems. In these systems energy is directly applied in production processes without intermediaries. That is the reason why a conventional analysis, in terms of demand and supply of energy products, is not capable of assessing all the aspects for the traditional sector in rural areas.

De Gouvelle presents an alternative category of analysis for energy products: the category of traditional energy solutions that concerns how traditional rural societies overcome problems associated to the realization of different agricultural and domestic tasks, and to satisfy domestic comfort. In this category every task (plowing, weeding, cooking, etc.) corresponds to one or various traditional energy solutions.

These traditional energy solutions intend to solve specific problems, while modern commercial energy products tend to perform various tasks, including the ones which can be solved by traditional methods. The necessity to increase the scale of modern commercial energy promoted some uniformity of the energy questions, while traditional solutions were characterized by a great diversity of options, depending on specific cultural and geographical circumstances. The systematic substitution of solutions for traditional energy by commercial energy can give rise to a crisis. The results of these practices are disappointing and frequently discriminating as they tend to standardize solutions without taking into account cultural and geographical aspects. The discussion on traditional energy solutions in the literature is mainly related to appropriate technology.

Electricity is one of the main forms of modern commercial energy products and has penetrated all aspects of modern live, even in the remote rural areas. Electricity distribution has been implemented in society trough large centralized production systems and has in the increases of scale its feasibility. This led to a model of centralized generation with radial distribution with economics of scale. This model is not appropriated for rural electricity supply systems that are mainly characterized by dispersed low-income consumers and low demand for electricity. These factors plus the high installation cost make rural electrification commercially unattractive. Mechanisms exclusively based on the market will not induce companies to invest for these consumers.

This finding is particularly important in countries where the electricity sector consists of private agents who have as their first goal the maximization of profits. Haanyika [7] analyzes the participation of the electricity sector in rural electrification in nine countries across Latin America, Africa and Asia by comparing the reform of the electrical sector in the 1980s and he showed that the private sector will not solve rural electrification problems on its own.

Governmental incentives are necessary through subsidies and the establishment of a regulatory authority to balance the needs of the private firms with the demands of rural electrification. The author also observes that utilities tended to focus on grid extensions even where decentralized systems are more suitable. Rural areas require a broader view on energy planning, far beyond the capability or interest of most electricity companies. It is also anticipated that dedicated rural electricity (RE) authorities will be more prudent in the management of RE resources. Under the new set-up, it would be easier to “ring-fence” RE finances in an environment of resource scarcity and of potential resource diversion to other priorities of government programs. Rural electrification has been executed mostly by vertically integrated state-owned power companies that have depended on economies of scale to cross subsidize RE activities [7].

Rural electrification as a public service by itself is not easy to assess. In order to obtain social, economic and environmental benefits, rural electrification must be integrated with rural development. But economic benefits are obtained more easily when there is an existing infra-structure such as roads, commercial availability of equipment and financial services which stimulates agricultural production in electrified areas. Utility providers acting as rural electrification agents have limited capacity to integrate rural electricity (RE) with components that increase energy consumption, such as technical assistance, social, health and educational services. RE requires a broader vision and scope, far beyond the interests of providers of utilities. Utilities sell energy and are not development agencies [7]. Therefore, simplified economic assessments are not sufficient to understand and solve the RE problems.

2.1. Rural electrification in Brazil

As was shown in the introduction, data from the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística – IBGE) show that there are over 163,000 households in the Amazon without electric illumination [5].

Over 155,000 (or 95%) of these households are situated in the rural areas. However, these numbers do not take into account how this electricity is provided for lighting. It can be furnished through an electricity utilities service supplier such as an electricity distributing company (EDC) or by an alternative form of electricity generation.

It can be inferred that the number of households not connected to the utilities service provider is far more. For example, in the state of Amazonas, the largest state in the region, there were in 2009 over 16,000 households in the rural areas without electric lighting and 138,000 with some form of electric illumination registered in the IBGE’s database. The database form the association of electricity distributing companies shows that there were only 17,690 rural consumers attended by the utilities companies in 2008 in the state of Amazonas [8]. That means that under 13% of the 138,000 households with the electric lighting is provided by the EDC in this state.

This confirms the data presented by Andrade et al. [2], as they show that there is a connection deficit of over 50,000 consumers in the state of Amazonas to be attended by electricity utilities provider through rural electrification initiatives.

Another example is the state of Pará, the second largest one in the Amazon, where the statistics listed 92,000 household without electric light and 387,000 with some form of electric illumination in the rural area. The EDC in Pará attends only 99,730 rural consumers with service, thus only 25%. The target of the EDC in Pará is to attend 140,000 consumers through rural electrification [9].

There is no precise data of the exact amount of households without electricity services. Di Lascio and Barreto [10] estimated in 2009 the need to attend 769,270 households in the Amazon. The Brazilian Ministry of Mines and Energy defined the target to attend 310,000 households from 2010 to 2011 in the Amazon.

The total amount of rural consumers attended by the EDC’s in the Amazon was approximately 300,000 by 2008 and that is less than half of the 752,000 households that have electric lighting. So we conclude that there is a demand to attend at least 607,000 households in the rural Amazon with some form of regular electricity service. Table 1 presents the demand for regular rural electricity service for the main states in the Amazon.

Can this demand be attended by the electricity sector through its electricity distribution companies?

As Brazil is a federation of states, the electricity sector has been traditionally divided into federal owned generation companies and state owned distribution companies and was operated under a monopoly structure.

The electricity distribution in the urban and rural areas was the responsibility of vertically integrated state owned power companies and they depended on economies of scale to cross-subsidize rural electrification [7].

This model suffered a change when a reform of the Brazilian electricity sector occurred in the 1990s and this had a direct effect on the rural electrification efforts as it took away the possibility to cross-subsidize.

This reform followed a world trend that started in the 1970s in Chile and was based on free market theories, which consider energy as a commodity, against the long standing vision that considers electricity an integrated service [11].

The reform had a strong focus on stimulating market mechanisms. Consequently social considerations such as universal access and rural electrification were put aside.

Table 1
Estimation of demand for electricity service in the Amazon.

Rural areas	Households with electric light	Attended by EDC	Households without electric light	Demand for RE
State of Amazonas	138,000	17,691	16,000	136,309
State of Pará	387,000	99,730	92,000	379,270
Amazon region	752,000	300,000	155,000	607,000

In Brazil the reform transformed the verticalization of energy companies and led to privatize 60% of the distribution and 20% of the electricity generation market [12].

At the end of the reform process 20 electricity distribution companies (EDC) were privatized including one of the mayor EDC in the Amazon in the state of Pará. Although the reform has been implemented for more than one decade, there are few studies on the effects of privatizing on the improvement of the electricity sector. Silvestre et al. [13] present a methodology to analyze the consequences of the privatization of electricity distribution companies in the Northeast of Brazil assessing consumer service and shareholder return, but there are no studies on the consequences for rural electrification.

The reform of the electric sector in the 1990s failed to increase the offer of electricity and in 2001 Brazil faced a mayor electricity crisis that threatened the economy with the possibility of blackouts all over the country. The privatization model of the electrical sector was not able to guarantee the generation's expansion, as needed. From 1990 to 2000, the electricity consumption had increased 44.6%, while the installed capacity increased only 28.5% [14].

The 2001 crisis led to a re-discussion of the sector model and opened new perspectives for renewable energy and rural electrification through universalization of electricity services.

2.2. Universalization of access to modern electricity service

Universalize access to modern electricity means making service accessible to all social segments without limitations regarding social, economic, cultural or geographical constraints. The Brazilian legal framework that regulates the electricity sector since 1995 states that expansion of electricity services must be carried out by the supplier with his own means and risk and that the consumers need only to pay their bills.

But this is not exactly what occurred. In practice, the consumer was financing grid extension. This situation changed in Brazil in 2002 when the responsibility of universalization was attributed to the state by law. Universalization of public electricity service seeks to achieve the general supply of electrical energy to reach progressively the number of consumers that were not included due to their distance to the distribution network or their inabilities to pay for normal tariffs [15].

The Brazilian federal government started a national rural electrification program called “Luz para Todos” or Light for All (LfA) in 2003, in order to achieve what was stated by law and to implement universalization until 2008. The program prioritized household's electrification in regions with a low Human Development Index (HDI) and low distribution coverage.

At the time LfA was created, its orientation towards rural electrification was clearly stated, as priority was given to: (i) municipalities with electricity coverage lower than 85%, (ii) rural electrification projects that benefit people affected by dams, (iii) rural electrification projects that focus on the productive use of electricity and promote integrated local development, (iv) rural electrification projects in public schools, health centers and water supply plants, (v) rural electrification projects designed to meet rural settlements electricity needs, and (vi) electrification projects for the development of family farming [16].

When the LfA was created, the EDC's basically considered grid extension as the means to supply electricity to rural areas. The website of the Ministry of Mines and Energy announced in December 2010 the conclusion of 2.6 million power connections to households in Brazil, wherein 493,000 families from the Brazilian Amazon.

By 2009, as the grid extension approach reaches its limits, the goals of the rural electrification program became harder to achieve. This makes sense since the isolated communities, which are the most difficult to reach, have been left to the final stage [17]. Estimates of the federal government showed in the beginning of the LfA program that there were about 300,000 households in the Amazon region that should be supplied with some form of decentralized electricity generation. The initiatives of this program with decentralized generation up to 2010 were only experimental and will be discusses in Section 4.3.

In order to discuss rural electrification through decentralized generation it is necessary to understand the limits and shortcomings of the institutional framework of the Brazilian electricity sector.

3. Institutional framework for decentralized electricity

The electricity sector is composed of public and private companies that interact in diverse forums to formulate energy policies. The main institutions are the Ministry of Mines and Energy (MME), the Brazilian Electricity Regulatory Agency (Agência Nacional de Energia Elétrica – Aneel), the National System Operator, Electric Power companies, and Utility providers or electricity distribution companies (EDC), along with various specialized councils. Besides these major agents the sector has independent producers, individual producers and rural electricity cooperatives.

The electricity system in Brazil is divided into interconnected and isolated systems. The large interconnected system is responsible for about 96% of the total installed capacity of 116 GW in 2011, and covers the Southeast, Center West and Northeast of Brazil. The backbone of this grid is a continental wide transmission system that is interconnected to 177 large hydroelectric and over 1200 thermal electricity units forming a complex hydrothermal system with very competitive tariffs. Apart from the interconnected system there is another special system to attend the other 4% of the Brazilian market that is not interconnected to the national backbone. These not interconnected systems are mainly located in the Amazon and are called the isolated systems.

3.1. Isolated systems

The isolated systems consist of 300 electrically isolated distribution networks, mainly installed in the Amazon region in the north of Brazil. They have predominantly been generating thermal electricity for supplying most of the state and municipal seats of governments in the Amazon. The cost for generating electricity of these isolated systems is very high due to the high price of fossil fuel and the logistics for transportation. The service is expensive, due to the inefficient functioning of motors (low load) and their advanced ages. All of these conditions increase the operation and maintenance costs that are considered the highest in the Brazilian system. Besides that, the great majority of consumers have a

Table 2
Types of classes of individual systems.

Classes	Reference daily consumption (Wh/day)	Minimum autonomy (days)	Minimum available power	Guaranteed available energy monthly (kWh)
SIGFI13	435	2	250	13
SIGFI30	1000	2	500	30
SIGFI45	1500	2	700	45
SIGFI60	2000	2	1000	60
SIGFI80	2650	2	1250	80

Source: Aneel [22].

very low family income, completely incompatible with electricity generation costs in the region [18].

Andrade et al. [2] estimates that the forecast fuel consumption for 2010 was 1.3 billion liters of medium oil (diesel and OCTE) and almost 1 million tons of heavy oil (combustible oil and heavy PGE) to generate thermoelectricity in the isolated systems via turbines in the larger municipalities and a large number of small diesel oil generators that are wasteful in terms of fuel due to their age and low efficiency.

In order to guarantee a final consumer tariff compatible with the rest of Brazil's interconnected grid, the costs for generating electricity is shared with all of the consumers through the fuel consumption account (Conta de consumo de combustível – CCC). This financial compensation mechanism permits a subsidy to cover the acquisition cost of fuel for generating thermal electricity, having as its main contributors all the utility companies in Brazil which supply final consumers. The thermoelectric generation for small cities with a nonstop 24 h supply has a refund of the amount that exceeds the respective equivalent hydroelectricity cost. That is the amount of generating hydroelectricity that could substitute the total of the generated thermal electricity if the system would be interconnected to the national grid [19].

This fuel account (CCC) can only be obtained by utilities providers, authorized by Aneel [20], that offer 24 h service compatible with the agency standards. The CCC also can be used to promote renewable energy sources as is stated in the law for the isolated systems. The problem is that, up to now, this resource has not been able to give support to generation using renewable alternative sources, but only to diesel oil and fuel oil power plants [18].

While the CCC mechanism enables the supply of electricity in the isolated systems, it also inhibits the competitiveness of renewable sources of electricity in the region, as it alters the relative price of the options. One way of modifying the current scenario would be to use CCC resources to enable the viable supply of renewable energy to isolated communities, on a long term sustainable basis, rather than subsidizing fossil fuels [2].

Critics state that the CCC subsidizes the utilities to buy fuel, not to generate electricity. The CCC attends the major state seats of state governments in the Amazon, such as Manaus, Macapá and Rio Branco, who together have more than 2.3 million inhabitants and all the other important cities in the municipalities in the Brazilian Amazon.

The Brazilian National Electricity Regulatory Agency published in 2009 a budget of R$ 2.5 billion for the CCC [21].

However the isolated systems are basically to attend the urban demands for electricity. Its functioning is based on market mechanism where the consumer tariffs are regulated by the regulatory agency and its cross subsidy is implemented through the entities of the electricity sector. Despite being identified as isolated systems, they do not attend isolated population or communities in the rural areas.

The problem for the electricity distribution companies (EDC) is to attend the rural areas were conventional network extension is not a viable technological and economic option. There is no special institutional framework to attend rural villages, settlements and communities with alternative forms of decentralized generation. The only way EDCs can attend legally rural consumers through decentralized generation is through a special option that was created in 2004 to attend individual consumers.

3.2. Individual consumers

In 2004 the Aneel regulated the use of decentralized generation for individual consumers so that utilities providers could offer a new service for isolated households [22]. This service was introduced to promote the use of photo voltaic (PV) cells as a technological option for utilities (EDC) to attend isolated households. This option was a consequence of a program implemented to promote PV generation that will be discussed in the next section.

Aneel permitted five forms of attendance for individual electricity generation systems with intermittent sources (Sistemas Individuais de Geração de Energia Elétrica com Fontes Intermitentes – SIGFI) that are shown in Table 2.

Despite the regulation from Aneel there are very few individual systems installed. There are only 5 EDC's in Brazil that were authorized by Aneel to install SIGFI systems and the total amount of units authorized was 10,155. Of this amount, only 100 units were installed in the Amazon [23].

There is no data available to assess the effectiveness of this option. The number of installed units in the Amazon is very insignificant to make some conclusions.

3.3. Isolated communities and mini grid

There are thousands of small villages, settlements and communities in the Amazon that do not have any form of regular electricity service provided by utilities. It is very common in those villages to have a diesel generator set which provides villages with a precarious form of electricity through a micro grid maintained by the village itself, sometimes with some support from the municipal or state authorities. These decentralized diesel generator sets operate only in pre-defined hours, normally only from 18:00 to 22:00 h. The household normally has no kind of measurement of consumption and the fuel consumption is divided by all consumers.

Some villages have a quota of fuel provided by the municipal or state authorities. In some places the diesel generator set is operated and maintained by the municipality.

These systems are not recognized as service providers within the Brazilian institutional framework of the electricity system. There is not even a formal description of these systems. In some official documents they are called isolated communities, not to be confused with isolated systems. In this paper they will be referred as precarious systems.

The fees those consumers pay are far above the tariffs of the electricity utilities company in the areas with normal coverage. The amount paid by those consumers does not reflect the real consumption as there are no means to measure. The amount to pay is defined by the community and based on the number of electric equipment connected to the mini grid.

Table 3
Classification of systems.

Type of service	Costs	Provider	Functioning	Supplied to
Interconnected system	Tariffs	Utilities	24 h	Cities
Isolated systems in the major Amazon cities	Tariffs and CCC (FCA)	Utilities	24 h	Cities
Individual decentralized generation	Tariffs	Utilities (SIGFI)	24 h	Households
Precarious systems: mini grid decentralized generation not registered by Aneel	Division or donation	Community or local public authority	Under 24 h	Villages, communities, settlements

As a matter of fact, all communities with more than 100 households do have some kind of arrangement with the local community, municipal and state authority and electric utility company. By law this service cannot be considered electricity utilities service. Even if it is provided by an utilities company they cannot charge consumers tariffs. de Gouvello and Maigne [24] estimate that there are some 600 diesel generator sets in the Amazon that are managed by local utilities company or municipal entities. The amount presented by these authors is very conservative, since in the Amapá state alone there are 157 units working with fuel support from the State and the local EDC.

The precarious systems are not part of the institutional framework of the electrical sector and it is guaranteed by the communities or local government. There is no mechanism to subsidize this form of service. Not even the CCC can be applied, once the service does not attend the basic requirements from Aneel.

Table 3 presents the classification of the types of services that were discussed until now. It must be stated that only the first 3 options are recognized and organized by the electricity sector.

The next item will present the policies (programs and project) that were realized in the Amazon to promote alternatives for the precarious mini grid decentralized generation.

4. Programs in the Brazilian Amazon region

The high cost of decentralized generation with diesel fuel led to diverse governmental initiatives to change fuel for renewable sources.

The earliest research and development (R&D) activities on generating renewable and decentralized energy in the Amazon started in the 1980s. The technology and its implementation depended on the personal vocation of individual researchers, and the fees or sponsors depended on researchers engagements. One of the first documented experiences is from Harwood [25]. He developed various technological alternatives to generate electricity to supply river people in the Amazon, and his work on hydrokinetic energy is one of the pioneering ones in literature. There are also some surveys on the use of Amazonian vegetable oils for energy purpose which date from 1990 [26]. These were projects executed by individual researchers and only in the 1990s the Brazilian government started initiatives to promote R&D, capacity and knowledge building on decentralized generation with renewable sources in the Amazon that will be discussed in the next topic.

4.1. Research and development programs on decentralized generation in the Amazon

One of the first governmental R&D initiatives was the wet tropic program (WTP) implemented by the Ministry of Science and Technology in the 1990s. There was a demand to develop technologies for the economic use of biodiversity and energy alternatives for the wet tropics. The WTP energy projects basically financed biomass for energy purpose and photovoltaic energy. In the coastal region of the Amazon some installations with wind turbines were also implemented. None of the WTP project financed mini or micro hydropower systems (see Table 4).

Some communities had more than one provision of funding along these years. This happened because the institutions had to support initiatives for some years to integrate the project in local development initiatives and promote the productive use of the electricity in order to consolidate the projects. Some experiences were successful and are considered examples while others were abandoned.

The WTP contributed to create a R&D infrastructure for renewable energy in the Amazon as the main laboratories on renewable energy in the region were funded with its resources. The WTP was basically a technological research program without participation of the electricity sector, and after its conclusion no other specific governmental R&D program on renewable energy for the Amazon was proposed. Parallel with this research initiative, another model, called Prodeem, was put into operation by the electricity sector through the Ministry of Mines and Energy.

4.2. Prodeem

The Energy Development Program in States and Municipalities (Programa de Desenvolvimento Energético de Estados e Municípios – Prodeem) was implemented in 1994 by the Ministry of Mines and Energy to reach rural population which were not attended by the electric distribution grid [27]. Between 1996 and 2002 approximately 6000 photo voltaic systems were installed and after 2002, until the interruption of the program in 2003, other 3000 photo voltaic units were acquired [28]. Evaluations of the Prodeem scopes

Table 4
WTP projects executed between 1995 and 2004.

Technology	Description	Projects
Elsbet motor with vegetable oil	Amazonian vegetable oil to produce electricity with a 100 kW Elsbet motor	1
Photo voltaic	PV for residential and community use	8
Gasification	Experimental project on gasification of biomass	1
Biodigestor	Experimental project on biomass	2
Hydrokinetic	Experimental project with 500W hydrokinetic turbine	1
Hybrid solar diesel	Demonstrative 30 kW solar with 160 kW diesel generator set	1
Hybrid solar wind diesel	Experimental projects in the coastal region with 10 kW wind turbines, PV and diesel backup	3
Hybrid wind diesel	Experimental projects in the coastal region with 10 kW wind turbines and diesel backup	2

performed by government institutions do not clarify whether or not all the units were installed. The results achieved indicated several weaknesses in the formulation of the program's objectives [29]:

1. Photovoltaic technology prevailed over other more sound technological options.
2. According to the Brazilian institution that audited the program, 46% of systems installed were mislaid and 36% were installed correctly but soon stopped working. Therefore, the targeted number of population benefiting was not achieved. Moreover, the audit disclosed that technical training in the maintenance of the systems did not meet its objective.
3. The execution of Prodeem was made through an international public bid which involved the importation of all equipment. The participation of the national industry was limited to the supply of batteries and other parts with minor technological content.

The distribution of PV systems covered until 2000 a total of 2600 communities in Brazil. In the Amazon only 495 communities were covered. The units were installed basically in schools, medical stations, water pump stations and community centers. Besides the photovoltaic system, the Prodeem also purchased two wind turbines and two micro hydropower plants. However its share in total resources was negligible. The installation cost of the two micro hydropower plants was no more than 0.18% of total resources invested and all equipments were furnished by national manufacturers.

It is surprising that a program with the importance and amount of resources as Prodeem did not use less risky technological option such as micro hydropower with national manufacturers, with trained technicians. Instead, they preferred a technology with total dependence on imported products. It is emblematic that the symbol of the program is a photovoltaic solar panel, however there is no explicit preference for PV in the official project documents.

The execution of the program had various technical and operational problems. The technical problems were lack of qualified personal to install and maintain the equipment, and difficulties in acquiring spare parts. Besides this there were several operational problems due to the implementation model based on agreements between federal government and states, not foreseeing responsibilities in operation and maintenance of the units. It can be inferred that the problems arose from Prodeem's implementation model, which parted from the assumption that massive insertion of photo voltaic equipments would automatically provoke an increase in this market, and that this would resolve problems of installation, maintenance and lack of qualified skilled technicians.

The WTP was a research initiative and Prodeem was an initiative from the Ministry of Mines and Energy. Both of the programs had no clear interface with the electricity sector and there was provision on transferring responsibilities to the EDC and utilities.

In 2003 a new program for rural electrification was initiated with a clear participation of the electricity sector, local state government and federal government. The Light for All (LfA) national electricity program started promoting rural electrification through network grid extension. The next topic will present the Light for All program and its special initiatives on decentralized generation in the Amazon.

4.3. The LfA program with decentralized generation

The LfA program was created in 2003 and, as its own name indicates, the objective is to provide electricity to all citizens, particularly to those who live in rural areas.

The program had special guidelines to attend those communities that traditionally did not had access to rural electrification, such as, indigenous, maroon, small family farmers, especially the one affected by dams and the program priories municipalities with low electricity coverage and low Human Development Index (HDI).

The LfA program stipulated clear targets and deadlines and allocated funding to implement rural electrification. The program is executed by the Brazilian Electricity Company (Eletrobras) and its implementation model is quite different from the one used in Prodeem, as the execution was totally coordinated through federal state owned companies and a deliberative board which allowed the participation of community representation.

The program allows the use of alternatives to grid extension and permits also the option of decentralized generation through local mini grid with renewable energy for isolated communities, mainly in the Amazon.

These new options placed the electricity sector to a new technological and operational challenge. The technological challenge is related to the introduction of the small scale decentralized electricity generation with renewable energy.

The operational challenge resides in the fact that the government implements the program through companies of the energy sector, which traditionally work with grid extension. Thus, the scale of operation of these companies formed a culture of great projects and ventures that can be a barrier to the universalization that needs to attend thousands of small communities with a high degree of dispersion and with little ability to pay for energy services.

The federal government, aware of the challenges of attending the targets in the Amazon region, invited the academy to participate in an initiative to develop technological and management models for decentralized generation with renewable energy, and in 2003 the Ministry of Mines and Energy and the Ministry of Science and Technology launched a call for proposals to promote the implementation of demonstrative projects. Besides being the first joint initiative of these two Ministries, it also encouraged socioeconomic development of selected isolated localities, and also training human resources for operation, maintenance and management of electric systems.

The main universities and research centers in Brazil answered the government call and proposed installation of various types of generation technologies, as seen in Table 5. Most of the ventures funded came into operation in 2006 and the communities are still assimilating the technology installed. As a wide range of systems were used with various technological options, there is no way to reach a single replicable management model. There is a big difference in management, for example, among enterprises that have biomass as input and hydro energy systems. However, the first assessments show that enterprises that were implemented with a strong social intervention in communities tend to suffer fewer difficulties.

It must be noted that the projects were executed in communities with very low literacy rates and low HDI. Therefore the R&D team had to be multidisciplinary in order to train local skills in operating the systems, implement management and promote the productive use of electricity. One of the mayor questions of the LfA projects concerned the ownership of the installed equipment. Although a federal project, it was not clear if the final responsibility of the installed equipment would be the community or government. The local state utilities providers and the municipal authorities did not participate in the implementation of the project and did not assume any obligation. But ownership is not only a matter of technical responsibility.

The results of these demonstration units can be the base to deepen the discussion on the management of an implementation model and technological alternatives to attend isolated communities in the Amazon region. But unlike the earlier programs, it can be stated that these initiatives were not executed as mere electrification projects, once they also had to consider socioeconomic development of the localities [30].

Table 5
LfA demonstration projects with decentralized generation using renewable energy.

Technology	Description	Projects
Hydrokinetic turbine	1 kW hydrokinetic turbine for community use	1
Micro hydropower	50 kW micro hydro from local Amazonian turbine manufacturer	2
Stirling motor	5 kW stirling motor with biomass	1
Steam turbine	Production of electricity from waste wood in 200 kW steam turbine	2
Biodiesel	Production of biodiesel from vegetable oil	3
Hybrid solar, wind and diesel	Revitalizing a 2 kW PV, 30 kW diesel and two 10 kW wind turbines	1
Hybrid solar and wind	Installation of 3,3 kWp PV with 1 kW wind turbine	1
Biomass gasification	Gasification of Assai waste (*Euterpe oleracea*)	
Photovoltaic	19 kW PV for residential use	2
Vegetal oil	Use of palm oil in 92 kW diesel motors	1

Despite the fact that the project was executed by the Ministry of Mines and Energy, none of the upper initiatives had an input or counterpart of the EDC or utilities.

Within the actual framework this kind of initiative has no interface with the EDC that have the prerogative to distribute and sell electricity.

We can infer that in order to expand the decentralized generation there must be a change in the sector and or create other institutional form or actors to implement alternatives.

4.4. Other grass root initiatives

Precarious systems are all over the rural areas in the Amazon and its maintenance is very costly for local communities, even with the support of local municipalities and state government, to provide minimal services to improve life quality in these areas. As has been shown, the mayor governmental initiatives to replace diesel fuel had its impact on creating a local R&D infra-structure and experimented with diverse technological options and management models, but failed to involve the electricity sectors and trans passes the limitation of the actual institutional framework.

But the demands for electricity in these communities and its urge for endogenous development, triggers local creativeness and entrepreneurship. This is specially the case in the center of the Amazon highland where there is a large hydro energetic potential. This led to local technological development of a new hydraulic low head turbine suited to the Amazonian reality and the design of pico and micro hydropower plants with appropriate technology for dam construction and rural electricity distribution system.

As a consequence, since 2000 local initiatives were undertaken in the hinterland of the state of Pará to substitute precarious systems with appropriate hydropower. Over 44 pico and 12 micro hydropower plants were installed in the municipalities of Santarém, Belterra and Uruará in the state of Pará by local entrepreneurs and communities to attend their basic electricity needs. These systems attend approximately 580 families and have a total installed capacity of more than 700 kV A.

The consolidation of this technological alternative by local entrepreneurs permitted an upscale and induced the Regional Superintendent of the Institute for Colonization and Land Reform and the Municipality of Santarém to elaborate a project to attend the land reform settlements in the region. This led to the installation of 6 mini hydropower (MHP) with a total installed capacity of 820 kV A and a 252 km distribution network to attend 1630 families in the rural settlements [31].

However, despite the fact that the MHP's are in operation, they are not yet registered in the data base of the electric sector. Just like the precarious system, they are maintained by the local municipal authorities without input or participation of the EDC or utilities companies.

The proposed management model is the one of collective administration where the operation of the system is done by the proper community. However, the operation and maintenance of the systems are still coordinated by the municipality, because the mechanisms to implement the collective management have not yet been designed.

These grass root initiatives differ from the previous program and projects discussed as they derive from an initiative within the municipality to attend a specific demand of family farmers in a land reform settlement and a very strong participation of the local communities in their implementation.

The results of these grass root initiative are quite significant compared previous described initiatives. Very few projects implemented with funding from the federal government and the electricity sector promoted technological options based on hydropower. The Prodeem installed only 2 micro hydropower plants and the LfA initiative only supported 1 micro hydro and 1 hydrokinetic demonstrative unit. Nevertheless, these grass root initiatives also did not resolved the participation of the electricity sector.

5. Changing the paradigm – electrification or development

The current institutional framework of the Brazilian electricity sector was designed to supply consumers through EDC, who obtain electricity from large hydrothermal power plants. This centralized structure seemed very effective to meet industrial consumers and urban areas needs, but failed to promote rural electrification of widely dispersed communities.

Urban consumers can count on a complex interconnected electricity system regulated by independent agency to guarantee a fair tax and a stable service. Even the consumers in the isolated systems can count on financial subsidy to permit reasonable taxes.

It has been shown that small villages and communities in the rural areas of the Amazon have a precarious form of electricity supply that is not recognized and regulated by the electricity sector, and there are no institutional mechanisms to attend the basic electricity needs of those communities.

This precarious form of electrification with mini grid is sustained by local municipal and state authorities, as it is considered a basic social right for those communities because it permits minimum access to lighting, information, leisure and security.

A first paradigm change is in considering mini grid with precarious generation as an utilities service to be included in the institutional framework of the electricity sector. This measure recognizes and legalizes thousands of small units that are already functioning in rural communities without any support of the electricity sector.

But it is not only a question of increasing access to electricity services.

Els [30] shows that rural electrification project in traditional communities cannot consider energy as a simple commodity. There is a need to insert the electrification initiative in a system of interconnected actions to promote local community's development,

using the energy as an inductor of this endogenous process. So the problem passes to one of local development and its resolution has to use the appropriate instruments available.

It can be noted that the governmental projects and programs matured from pure technological research, as in the WTP, to projects that had to consider socioeconomic development of the localities. The grass root initiatives present a new element, fundamental in this paradigm shift, as they surged from action within the municipality to attend a specific demand with very strong participation of the local communities in their implementation.

In this section the discussion on rural electrification and local development is continued, appointing some lessons learned and new policies.

5.1. Lessons learned – institutionalizing new actors

The experiences in the WTP and LfA projects showed the importance of universities and research centers in the implementation of these initiatives. As they were essentially research projects they permitted alternative forms of implementation and conduction. The project executors tested diverse implementation models ranging from community based initiatives to post paid consumer models. Expressive participation of local communities showed to be determinant in project implementation [30].

Another important fact observed in the WTP projects is that the successful projects had financed efforts to integrate the generation of electricity into local development initiatives in order to guarantee sustainability. This same trend was noted in the demonstrative LfA projects and it can be stated that a substantial part of funding was used for local mobilization and organization. As a matter of fact, the most successful projects were executed as local development projects taking into consideration technical, socioeconomic and cultural aspects. Community ownership showed to be effective when there was a clear input and control of the local community in the design and execution of the initiative.

The composition of the project executors is also very determinative for its success. Project teams must be multidisciplinary in order to take account of the technological aspects of the electrification project and other fundamental aspects such as local participation and empowerment of the community, management models and ownership of community projects.

The project executors were mainly groups from universities or research centers and had the advantage that they were able to experiment diverse innovations on implementation and management, but on the other hand suffered with a lack of institutional support and continuity. This reinforces the necessity to institutionalize a new type of projects executors. This can be done with the introduction of special agents to implement rural electrification with decentralized generation on a municipal level, taking into account the specificity of their region.

The introduction of this new actor on a municipal level is necessary because of the EDC's lack of interest in promoting rural electrification with other means than grid extension. The EDC's also do not have the capillarity to manage small disperse mini grids, which attend villages where market factors are insufficient to guarantee the service. EDC's acting as rural electrification agents have limited capacity to integrate rural electricity with components that increase energy consumption, such as technical assistance, social, health and educational services [7].

On the other hand, municipalities actually are providing fuel and equipments to those villages without being considered agents in the institutional framework. The creation of municipal rural electrification companies or agencies are especially attractive if the municipality has abundant local renewable energy sources as it can reduce diesel fuel costs already paid by the municipality.

This new actor on a municipal level can be responsible for the planning, implementation and management or monitoring of mini grid decentralized generation.

Other new actors that should be institutionalized are the grass root organizations that manage and maintain the diverse grid rural electrification initiatives with renewable energy in the Amazon, especially the ones in the municipality of Santarém in the state of Pará. This kind of organization based on local participation, can be structured through cooperatives for rural electrification.

As shown by Gómez and Silveira [17] there are different needs and development stages among diverse communities and they also reveal that the Brazilian electricity system does not contemplate institutional diversity that can promote rural electrification for the Amazon region.

This conclusion is not unique for Brazil. Experiences in South Asia showed that a key barrier to extend and sustain off-grid rural electrification is a lack of appropriate institutional models. Most of the off-grid programs are implemented through NGOs or local level institutions, but there has been no separate policy framework for the off-grid based rural electrification initiatives [32].

It is now necessary to complement the experiences so far acquired with the development of a new regional approach in which new actors could have a crucial role to play. In the next section the specificities of these two new actors are discussed.

5.2. Cooperatives of rural electrification

Decentralized delivery by local cooperatives is seen as an alternative "third-way" approach in certain developing countries, due to the given inadequacies of large state utilities, coupled with some recent failures to incentive private sector investment in rural electrification [33].

Cooperative systems have proved to be successful in many countries when it comes to promoting electrification and dissemination of renewable energy technologies [17].

As is shown by Yadoo and Cruickshand [33] the formation of local cooperatives to increase rural electricity access is not new. The majority of rural USA was electrified in this manner in the middle of the past century. In the mid-1930s 90% of rural homes lacked electricity and locally owned rural electric cooperatives were able to double the number of rural electric systems in operation, triple the number of consumers connected and increase the amount of grid distribution lines more than five-fold within 13 years. By 1953, over 90% of the USA's farms had electricity.

The rural electrification cooperatives arose in Brazil in the beginning of the 40s, in the South of the country, by the initiative of small population nuclei. Initially intending to provide electricity for small towns or residences in isolated areas, the cooperative system expanded, such as in other countries, in many cases due to the natural growth of the countryside and cities, attending consumers neglected by the EDC's. The rural electrification cooperatives could expand their activities and, in some cases, act as electricity utilities, although their status in the electricity sector was that of a consumer of local supplier utilities.

The reform of the Brazilian electricity system permitted the maintenance of the rural electrification cooperatives and allowed the change of their legal status, from consumers to agents, inserting them into the regulated market. The challenge to integrate the cooperatives within electricity sector was to conciliate the diversity of existing cooperatives and the complexity of the electricity sector [34].

There are 138 cooperatives for rural electrification in Brazil, with over 550,000 members. The cooperatives were very important for the implementation of rural electrification in the south of Brazil. But the introduction of new cooperatives has some barriers in Brazil. Prado [35] states that hardly new cooperatives will emerge in the

Table 6
Mini grids initiatives with local organization or cooperatives and decentralized generation using MHP.

Site	Capacity (kV A)	Families
Açacal do Prata – Belterra Pará	80	80
Cachoeira Aruã – Santarém Pará	50	49
Corta Corda – Santarém Pará	150	180
Água azul – Santarém Pará	120	50
Piranha – Santarém Pará	150	350
São João e Santo Antônio – Santarém Pará	150	190
Santa Rita – Placas Pará	90	180
Sombra Santa – Placas Pará	160	380
Total	950	1459

actual model of the electricity sector model due to the restriction imposed by the electricity distribution company's, the new legislation and the high level of electricity coverage in the South and the Center of Brazil.

Unlike the South, in the Amazon the figure of the cooperative for rural electrification is not widespread. Data from Aneel shows that there are no acting cooperatives for rural electrification in the Amazon.

This can be partly explained by the different land occupation process in the South of Brazil and in the Amazon. The South was mainly occupied by immigrants that settled in small communities. It was in the South that the agricultural cooperativism found mayor space to develop itself, due to the strong influence of Italian German immigrants that "transplanted" their associative experience on competitive cooperative systems [36].

The model of occupation that characterized the formation of the Amazonian territory was marked by surges of exploation of extractive products for export [37]. This colonization process did not instigate an endogenous development process, that characterized the development of the South of Brazil, but favored large landowners and enterprises orientated in exporting spices, rubber, wood and minerals.

The endogenous development initiatives arouse form the descendants of the extractivist rubber tapper laborers who were abandoned by their employers after the globalized economy directed its commercial interests to other products. The first local cooperative processes in the North established themselves in the beginning of the 20th century through extractivist cooperatives and encountered various obstacles in its growth; Obstacles that range from the difficulties due to the long distances, difficulties of infrastructure and access to consumer markets and even the absence of specific policies for the sector and region [36].

Understanding the difficulties of community development in the Amazonian context is fundamental to support cooperative initiatives for rural electrification. Diniz [38] elaborated a multi-case study methodology to assess local development projects, analyzing collective management and organizational environment of small cooperatives of forest products in the Amazon. This methodology can be helpful to understand the difficulties of implementing grass root initiatives of cooperatives of rural electrification, specially in the Amazon.

Even when a grass root organization succeeds in promoting community based rural electrification initiatives, there are diverse bottlenecks that obstruct the consolidation of the projects. There are several community bases initiatives with micro hydropower and mini grid attending their small villages that *de facto* function as cooperatives, but are registered as association due to the bureaucracy to legalize the project. Table 6 lists 8 micro hydropower sites and attend 1459 families that are actually maintained by associations in the state of Pará and need to be institutionalized [31].

The mini grid initiatives are not restricted to micro hydropower technology. There are some experiences in the Amazon with biomass residue that also need to be institutionalized through cooperatives. Rosa [26] describes an interesting initiative with vegetable oil and Pinheiro et al. [39] presents a case study of the electrification through a small 50 kW biomass-based power plant, directly firing residues provided by the local economic activity. Nevertheless biomass based systems needs a more elaborated approach as it depends directly on the local economic activity and organization.

In spite of all the difficulties listed above, cooperatives for rural electrification are a viable alternative of implementing decentralized generation in the Amazon. The cooperative can, apart from the electrification, offer other services for its client and, more important, make possible the productive use of the generated electricity and increment social capital and local organization.

5.3. Rural electrification agency

The previous section proposed the introduction of a special agent to act in the municipality to promote rural electrification with decentralized generation. It can also be an federal or state institution, but to be effective it necessarily requires a direct interface within the municipality.

There are diverse arrangements to implement this novel actor and this depends on the specificities of the municipality. Specialized municipal rural electrification companies or agencies are especially attractive if the municipality has abundant local renewable energy sources. It can be also effective to strengthen existing state or regional development agencies with skill to act in rural electrification or even increase the attributions of governmental bureaus for agricultural technical assistance and rural extension.

It has to be kept in mind that this is not about dissemination or promoting alternative energy technologies or creating markets for modern electricity generation equipment, but creating instruments to support local development through rural electrification.

This idea is reinforced by Kaygusuz who state that policies, programs and projects should start from an assessment of people's needs rather than a plan to promote a particular technology. The needs of different rural communities vary widely, and finding appropriate technologies and effective implementation strategies can be very site-specific [40].

Another precaution that has to be taken is not to transform this agent into an EDC. The most successful experiences for mini grids in the Amazon shows that distribution and daily operation are most effective when maintained by locals through associations or cooperatives. However, most of these organization lack specialized technician to realize more specific technical maintenance and other management tasks. Thus this new actor can have the attributes to plan, assist with fundraising, promote capacity building, guide project implementation, monitor and provide specialized technical assistance.

But the main purposes behind this new agent is that with the creation of this specific entity within the electricity sector, special treatment can be given to rural electrification. Decentralized generation with mini-grid projects, just as the thousands of precarious systems in the Brazilian hinterland maintained by local communities, are not part of the institutional framework of the electricity sector and thus have no access to subsidies and funds, that are guaranteed to all EDC consumers.

It is known that mini-grid projects are costs expensive and the remoteness of projects increases the capital cost, operation and maintenance costs and in turn the cost of generation and supply. Traditional economic analysis based on investment return through tariff will show that these projects are not viable.

This is not unique to Brazil. Palit and Chaurey [32] shows that off-grid projects in many South Asian countries are not covered under the regulatory regime and the benefits of any cross subsidization can not be extended to rural consumers of such projects.

The creation of a rural electrification agency together with the institutionalizing of cooperatives for rural electrification can permit new forms of public and community partnership to promote local development.

6. Conclusion

This paper presents the situation of rural electrification in the Brazilian Amazon and the initiatives undertaken to bring electricity for the thousands of isolated communities that need to have a form of decentralized electricity generation to attend its needs.

First an overview of the problems of rural electricity are discussed and its specificities in the Brazilian Amazon. In the next section the Brazilian institutional framework that organizes the decentralized electricity generation is described with its various limitations. The diverse initiatives undertaken to attend the rural communities in the Amazon since the 1990s are described, as well as how these initiatives are linked to the policies for rural electrification.

The experience of WTP showed also that most of the successful projects were monitored during several years and received more than one provision of funds. The R&D team that implemented the project had to attend to technical aspects and also had to help to organize its management model. Another important fact is that the successful projects had to finance efforts to integrate the generation of electricity into local development initiatives in order to guarantee sustainability. This same trend was noted in the demonstrative LfA projects and it can be stated that a substantial part of funding was used for local mobilization and organization. As a matter of fact the most successful projects were executed as local development projects working on technical, socioeconomic and cultural aspects. Community ownership showed to be effective when there was a clear input and control of the local community in the design and execution of the initiative.

Analyzing the WTP and the preliminary results of LfA, it can be inferred that sole market mechanisms are not sufficient to guarantee economic sustainability. All of the projects presented a financial picture which showed the impossibility of a return on the invested capital with the commercialization of the produced electricity. These results confirm Haanyika's analysis, as the author states that in order to have social, economic and environmental benefits from rural electrification, the efforts have to be integrated with local rural development.

This can be one of the reasons why the traditional EDC's showed lack of interest in promoting rural electrification with other means than grid extension.

Different than the governmental program other grass root initiatives in Central Amazon led to local technological development of a new hydraulic low head turbine suited to the Amazonian reality and the design of pico and micro hydropower plants with appropriate technology for dam construction and rural electricity distribution system.

However, despite the fact that this technological option haves several systems in operation, they are not yet registered in the data base of the electric sector. Just like the precarious system, they are maintained by the local municipal authorities without input or participation of the EDC or utilities companies.

This reinforces the necessity to introduce new agents to implement rural electrification with decentralized generation on a municipal level as the municipalities actually are providing fuel and equipments to those villages without being considered agents in the institutional framework.

The challenge is to make the necessary paradigm change to (1) treat rural electrification as local development, (2) institutionalize already existing mini grids within the electricity sector, (3) execute these projects with the support of multidisciplinary teams to empower local management and promote productive electricity use with clear input and control of local community to promote community ownership. This can be obtained only by implementing policies on a local municipal level. Policies to introduce new agents such as municipal rural electricity and development companies or agencies and to empower local communities to implement cooperatives for rural electrification can be an option to succeed where federal programs were only experimental.

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